

LEVEL SENSORS

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## LEVEL SENSORS

### FIELD OF THE INVENTION

5        This invention relates to a method and apparatus for measuring liquid levels.

### BACKGROUND OF THE INVENTION

10        Many different types of level sensors are available, and these rely upon a variety of different physical principles. One reason for the large variety of sensors is that level sensors are required in numerous different environments for many different purposes, and few level sensors are versatile enough to have a wide range of use. Thus, for example, some level sensors merely detect whether or not liquid has exceeded a predetermined level, whereas some applications require measurement of liquid level throughout a

15        range. Some level sensors operate over an inadequate range, and others with inadequate resolution. Sensors which operate accurately over a predetermined range can be excessively expensive, particularly for wider ranges. In some cases, the structure or physical principles of operation are incompatible with the environment in which the sensor is intended to be used.

20        Some known forms of liquid level sensor are level switches which operate using optical principles. For example, the sensor may be a transparent device which incorporates a light emitter and a light receiver so arranged that light from the emitter is totally internally reflected by the outer wall of the

device to the receiver when the sensor is surrounded by air. However, when immersed in liquid, the light from the receiver is refracted into the liquid, so the light received by the receiver diminishes, thus providing an output indicative of the immersion. See for example GB 2 036 326 A.

5           Such arrangements are not, however, suitable for indicating varying liquid levels. It would of course be possible to provide a number of such level switches spaced in a vertical direction in order to provide for a varying level indication. However, this would be expensive and difficult to assemble. The physical size of each switch would preclude the possibility of mounting them  
10       in close proximity, thus resulting in an arrangement which is lacking in resolution and/or compactness.

          It would be desirable at least to mitigate the problems referred to above.

## 15       DESCRIPTION OF THE INVENTION

          Aspects of the present invention are set out in the accompanying claims.

          According to a further aspect of the invention, a level sensor incorporates an array of light emitters arranged along a direction which, in  
20       use, is at least approximately vertical, and an array of light receivers distributed along a substantially parallel direction, each receiver being operable to receive light from at least one emitter. The emitter and receiver arrays have a common transparent housing which is capable of totally

internally reflecting light from the emitters to the receivers by an external surface which is preferably continuous and straight in the aforementioned direction.

Such an arrangement provides for ease of manufacture, especially if  
5 the housing is formed using a moulding, extrusion or potting process. An inexpensive unitary device provides for detection of various different levels. Using a continuous, preferably straight external surface means that the positions of the emitters and receivers with respect to the length of the housing are not critical, and also facilitates cleaning of the sensor, which can  
10 be very important in certain environments, such as those involving foodstuffs. These advantages are further enhanced if, in accordance with a preferred aspect of the invention, the outside profile of the housing is substantially uniform throughout the length over which level sensing takes place.

Varying liquid levels can be determined by operating the light emitters  
15 (preferably at respective different time intervals), and determining which receivers receive a significant amount of light (indicating that the housing close to receivers is not immersed in liquid), and which receive a diminished amount of light (indicating that light is being refracted out of the housing by liquid in the region near the receiver).

20 Further preferred features of the invention enable additional cost reduction and ease of manufacture.

According to one preferred feature, the emitters and receivers are respectively driven and enabled by at least one shift register. Use of a shift

register (which can be implemented using very inexpensive components) reduces the wiring requirements of the circuit as compared with providing individual driving and enabling circuits. There may be respective shift registers for the emitters on the one hand and the receivers on the other hand.

5 However, the preferred embodiment incorporates a shift register which both drives the emitters and enables the receivers.

According to a further preferred feature of the invention, the circuit for operating the level sensor comprises a plurality of individual circuit boards of identical, modular construction, each circuit board containing a portion of the  
10 shift register. This means that level sensors of differing lengths can be built using common components, by appropriate selection of the number of modular circuit boards, thus reducing costs.

According to a further preferred feature of the invention, each receiver is operable to receive light from at least two emitters at respective different  
15 heights, the emitters being, in use, operated at different time intervals. Thus, a single receiver can indicate whether or not the liquid has reached any of two different levels. Additionally, or alternatively, each emitter is arranged to illuminate two separate receivers, each of which can be enabled in respective different periods. Accordingly, a single emitter can be used for determining  
20 whether the liquid has reached either of two different levels. By combining these features, for a given resolution, the number of emitters and receivers can be halved, thus further reducing costs.

In a still further preferred feature of the invention, the circuit for operating the level sensor is arranged to determine not only whether the liquid has reached certain discrete levels corresponding to respective emitter/receiver light paths, but also whether the liquid has reached one or more intermediate levels, in accordance with the amount by which the light received by a receiver has diminished due to refraction of some of the light into the liquid due to partial immersion of the adjacent sensor region. For a given number of emitters and receivers, this can at least double the resolution of the sensor.

According to a still further preferred feature of the invention, the level sensor incorporates a memory storing calibration data which is used in order to determine whether the amount of light received by a receiver indicates that the respective location on the level sensor is or is not immersed. This therefore compensates for manufacturing variations which can cause respective light emitters to emit different amounts of light. The receivers may also have different sensitivities, which can be compensated by the calibration data. There may be individual calibration data values for the respective emitters and/or for the respective receivers, but in the preferred embodiment, there are stored respective calibration data for the different emitter/receiver light paths.

According to a further preferred feature of the invention, the effects of ambient light are compensated when evaluating the outputs of the light receivers by taking a separate ambient light measurement. In the preferred

embodiment, each reading from an emitter/receiver pair is compensated by a separate reading from the same receiver without the respective emitter being operated; that is, individual ambient readings are taken for the different receivers. In a particularly preferred embodiment, the ambient reading is  
5 combined with the calibration data mentioned above in order to compensate both for individual variations in circuit components and ambient light.

According to a still further feature of the invention, the influence of temperature is also compensated. This is especially valuable in arrangements in which intermediate levels can be detected by virtue of the amount of light  
10 received by the receivers, which operation can be significantly influenced by temperature. Preferably, temperature compensation is carried out by taking readings from an emitter/receiver pair in a known state (preferably non-immersed) and comparing these readings with calibration data for the corresponding devices to derive a temperature compensation factor.

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## DESCRIPTION OF THE DRAWINGS

Arrangements embodying the invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a perspective view, partially broken away, of a level sensor  
20 in accordance with the invention;

Figure 2 is a cross section through a modified version of the sensor of Figure 1;

Figure 3 shows the circuit of the level sensor;

Figure 4 shows part of a shift register of the circuit of Figure 3; and

Figures 5A and 5B illustrate the cross-sections of other modified embodiments and possible light paths therein.

## 5 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to Figure 1, a level sensor 2 comprises an elongate housing 4 intended to be mounted in a vessel in a generally upright orientation. The housing contains one or more circuit boards 6 carrying an array 8 of light emitters and an array 10 of light receivers. The elements of each array are spaced apart in the direction of length of the sensor 2. Each of the light emitters 8 is positioned intermediate the height of an adjacent pair of receivers 10.

The housing 4 is formed by insert moulding around the circuit board 6 and comprises a transparent material, for example an acrylic material.

15 The light emitters 8 may comprise surface-mounted infra-red emitting LEDs. The light receivers 10 may comprise surface-mounted photo-transmitters responsive to infra-red light. (The term "light" is intended herein not to be restricted merely to visible light, but also to extend to all other wavelengths of electromagnetic radiation, and other terms, such as  
20 "transparent" should be interpreted accordingly.)

The refractive index of the housing 4, which may be similar to the refractive indices of the plastic housings of the emitters 8 and receivers 10, is significantly different from the refractive indices of the liquids with which it



is intended to be used. The refractive index and the positions of the emitters 8 and receivers 10 are such that each receiver can receive light which has been emitted from either one of two adjacent emitters 8 and then internally refracted by the outer surface of the housing 4. Similarly, each emitter can  
5 illuminate two adjacent receivers 10 by means of light which has been internally reflected. Examples of such light paths are shown at 12. It will be noted that the light paths are in respective different non-parallel planes.

The circuit board 6 also carries electrical components (not shown in Figure 1), and principally a shift register for driving the emitters 8 and  
10 enabling the receivers 10. The components are connected to a control circuit housed within a cap 14 at the top of the sensor, which receives power and sends an output signal via wires 16.

Figure 2 is a cross section through a modified arrangement, in which the housing 4 comprises an outer cylindrical wall 18, for example made of a  
15 PVC or polycarbonate extrusion, in which the circuit board 6 is mounted. Following this operation, the housing 4 is filled with a potting compound 20, for example a clear two-part epoxy, of similar refractive index to the transparent wall 18. In this embodiment, the surface-mounted emitters 8 and receivers 10 have been replaced by through-hole components which are  
20 angled towards each other so as to increase the angle of incidence of the light emitted thereby to the normal to the wall 18, thereby increasing total internal reflection of the light.

In both embodiments, the emitters 8 and receivers 10 are spaced apart as far as possible in order to increase this angle of incidence. For this reason, in the embodiment of Figure 2, the thickness of the wall 18 is preferably relatively small.

5           The embodiment of Figure 2 may be easier to manufacture, particularly if the level sensor is intended to be used in fairly hostile environments, in which case the cylindrical wall 18 can be made of protective material.

          Referring to Figure 3, the circuit of the level sensor 2 comprises  
10           principally a control circuit 30 and a shift register 40. The shift register 40 comprises a plurality of substantially identical sections, one of which is shown in Figure 4. Each section receives as its input the output from the last stage of the preceding section. Each emitter 8 is connected between a respective shift register output and a common supply voltage rail 42. Each  
15           receiver 10 is coupled between a respective shift register output and a common output rail 44. The emitters 8 and receivers 10 are coupled to respective alternate outputs of the shift register 40.

          The control circuit 30 comprises a microprocessor 32 which has a clock output which clocks the respective shift register sections via a common  
20           clock rail 46. The microprocessor also has an output line 34 which transmit data serially into the input of the first shift register section. By producing clock pulses on the line 46, any data sent to the first stage of the shift register is gradually clocked along the shift register, thus selectively driving the

successive emitters 8 and enabling the successive receivers 10. When one of the receivers 10 is enabled, an output signal representative of the degree of illumination of the receiver is provided on output rail 44 to a variable gain element 36, whose gain is controlled by the microprocessor 32, and then to an  
5 analog-to-digital converter 38 forming part of the microprocessor 32.

The microprocessor 32 is also coupled to a non-volatile memory 39, such as an EPROM, which stores calibration data. The microprocessor provides output data serially on an output line 50 indicative of a liquid level detected by the sensor 2. This can for example be sent to a digital display, a  
10 voltage (digital-to-analog) converter or a 4-20mA drive converter.

The operation of the level sensor will now be described, starting with an explanation of individual elementary operations. It is assumed that the devices 8 and 10 are collectively referred to by indices  $i$ , ranging from device 1 connected to the first shift register output to the last device  $n$ . Each light  
15 path has an index corresponding to the lowest index of the two devices defining the path.

#### Ambient Reading Operation

Assuming that the  $i^{\text{th}}$  device is a receiver and an ambient reading is required for this device, the microprocessor 32 sends a binary value "1" followed by zeroes to the shift register 40, and issues  $i$  clock pulses to cause  
20 the "1" to travel to the  $i^{\text{th}}$  device. After a brief settling interval, the microprocessor then reads the value appearing at the output of the analog-to-digital converter 38. This ambient reading will be referred to  $AR_i$ .

### Light Path Reading

Assuming that a reading is taken of the  $i^{\text{th}}$  light path between the  $i^{\text{th}}$  device and the  $(i+1)^{\text{th}}$  device, the microprocessor transmit the binary value "11" followed by zeroes to the shift register 40 and  $i$  clock pulses so that these  
 5 digits reach the appropriate devices. After a brief settling time, the microprocessor reads the value of the analog-to-digital converter 38. Its value will be referred to as a light path reading  $LP_i$ .

### Compensated Reading Operation

In order to derive a sensor reading which is compensated for ambient  
 10 light, there is derived a compensated reading  $CR_i$  which is the difference between the light path reading and the ambient reading, i.e.  $CR_i = LP_i - AR_i$ .

Preferably, each compensated reading is derived by two immediately successive operations, one involving taking the ambient reading and the other involving taking the light path reading, so as to avoid the need to store these  
 15 individual measurements.

### Calibration Operation

After manufacture of the level sensor 2, but before sale, a calibration operation is performed in order to derive the calibration data stored in the memory 39. This involves deriving compensated readings  $CR_i$  for all  
 20 adjacent emitter/receiver pairs while the level sensor is not submerged, to obtain upper calibration readings  $UC_i$ , and then repeating the operation when the level sensor is submerged to derive lower calibration readings  $LC_i$ . Thus,

for each emitter/receiver path there is stored within the memory 39 two calibration data values.

As an alternative, the calibration operation can be carried out in the dark, and each calibration value set equal to the light path reading  $LP_i$ , rather  
 5 than the compensated reading  $CR_i$ .

#### Immersion Decision Operation

In use of the level sensor, a determination of whether the light sensor is immersed at a region adjacent the  $i^{th}$  light path between the  $i^{th}$  device and the  $(i+1)^{th}$  device, is made by obtaining the compensated reading  $CR_i$  and  
 10 then determining whether:

$$CR_i < (UC_i - LC_i)/TH,$$

where TH is a predetermined threshold quantity, e.g. 8. If the condition is met, i.e. little light is being received, then the relevant part of the level sensor is determined to be immersed. If the portion is immersed, then a variable  $I_i$  is  
 15 equal to 1, otherwise  $I_i$  equals 0.

#### Coarse Level Determination

The coarse level is evaluated by carrying out immersion decision operations at different levels  $i$ , and determining the minimum value  $k$  for which  $I_k = 1$  and  $I_{k+1} = 1$ . That is, the coarse level LC corresponds to the  
 20 highest level  $k$  for which both that level and the immediately adjacent lower level are submerged. Checking that both of two adjacent levels are immersed avoids possible errors due to drips on the side of the level sensor above the

liquid level. In a modification, additional lower levels could be checked if desired.

If the approximate level is known, for example from a former reading, then the new level can be determined by a search operation starting with the expected level and then checking alternately higher and lower levels, gradually extending away from the expected level, until the required conditions are met. If the level is completely unknown, a binary search procedure can be used.

#### Dirt Measurement

After the coarse level is determined, a compensated reading is derived for the light path two levels above the coarse level, i.e. the reading  $CR_{k-2}$  is determined. (This is assumed to be a reading at a location where there is no liquid adjacent the level sensor. This can be checked by determining  $I_{k-2}$ , and a different level selected if the assumption is incorrect.) This is then compared with the upper calibration reading  $UC_{k-2}$ . If

$$UC_{k-2} - CR_{k-2} > TD,$$

where TD is a predetermined threshold, this indicates that the reading is significantly lower than expected, taking into account the ambient light, suggesting the presence of too much dirt on the sensor. The control circuit then issues a warning signal (which could trigger an audible or visual alarm). If desired, this check could be performed for additional non-immersed light paths.

### Fine Level Determination Operation

Assuming no significant amount of dirt is found, a temperature compensation factor TC is then derived by performing the calculation:

$$TC = (CR_{k-2} - LC_{k-2}) / (UC_{k-2} - LC_{k-2}).$$

5            This temperature compensation factor thus represents the ratio between the actual range between the readings for the sensor when not submerged and when submerged, and the calibrated range. (The reading when submerged is normally low and assumed to be equal to the calibration reading  $LC_{k-2}$ .)

10           It is assumed that this ratio will be substantially constant for other  
positions on the level sensor, at least those closely adjacent the (k-2) light  
path.

Having determined that the  $k$  level is totally immersed, and the  $(k-2)$  level is not immersed, the extent of immersion of the  $(k-1)$  level is then determined. A temperature compensated reading  $TR_{k-1}$  is calculated as follows:

$$TR_{k-1} = CR_{k-1}/TC.$$

The level sensor adjacent the (k-1) light path is then determined to be not immersed if:

$$20 \quad \text{TR}_{k-1} > 3 (\text{UC}_{k-1} - \text{LC}_{k-1})/4,$$

or semi-immersed if:

$$(UC_{k-1} - LC_{k-1})/4 \leq TR_{k-1} \leq 3 (UC_{k-1} - LC_{k-1})/4,$$

or fully immersed if:

$$TR_{k-1} < (UC_{k-1} - LC_{k-1})/4.$$

Accordingly, it is possible to derive a fine level reading which, depending upon its determination, corresponds to the coarse reading k, the next level up, k-1 or an intermediate position between these two levels. With an appropriate construction and by using more intermediate threshold levels, a greater resolution could be achieved. It is however, noted that this fine level reading is optional, and could be omitted if the response characteristics of the devices are unsuitable, or if this precision is not required.

#### 10 Variable Gain

If desired, prior to taking a set of readings in order to calculate a level measurement, the microprocessor 32 may be arranged to adjust the gain of the variable gain element 36. This could be achieved by obtaining a compensated reading  $CR_i$  from one or more illuminated receivers and altering the gain in order to get a substantial reading. This enables the device to avoid analog-to-digital resolution errors by operating at an appropriate gain.

#### Circuit Structure

Referring again to Figure 4, the circuit of the level sensor is mounted on a plurality of circuit boards. The control circuit 30 is mounted on a first circuit board 60 housed in the cap 14 of Figure 1. The first two sections of the shift register 40 are mounted on a circuit board 62. Subsequent pairs of sections are mounted on circuit boards 64 of identical construction. To form level sensors of different lengths, fewer or more circuit boards 64 can be used.



In this embodiment, each section of the shift register comprises a single integrated circuit 70 (for example part number 74HC164), and each circuit board 64 carries two such integrated circuits. However, the circuit boards could incorporate fewer or more sections or integrated circuits.

5           If desired, the final receiver 10' of the array may be replaced by a resistor of predetermined value, so that the microprocessor 32 can sense when the last stage of the shift register has been reached. This will enable the microprocessor to operate using software which is common for different-length level sensors.

#### 10    Modifications

          Various modifications are possible. It is preferred for the level sensor housing to be circular in cross section, as shown in Figure 2, as this readily permits the divergent beam from the emitter to travel to the receiver by multiple paths involving total internal reflection. Other shapes are possible,  
15   however. The cross section may be elliptical or part-elliptical, or could be trapezoidal, for example as shown in Figures 5a and 5b. The profile of the cross-section is preferably substantially uniform along the length throughout which the emitters and receivers are distributed. Temperature compensation can be achieved by other means than those set out above, e.g. by thermistors  
20   in series with the emitters. To reduce the effects of ambient light, the housing or the potting-compound is preferably formed of material which is transparent to the wavelength (e.g. infra-red) used by the emitters and receivers but substantially opaque to other wavelengths.